SUBMARINE-BASED ACOUSTIC DOPPLER CURRENT PROFILER (ADCP) MEASUREMENTS OF THE ARCTIC OCEAN UPPER HALOCLINE, INCLUDING RIDER PROVISION FOR SUMMER 1997 SCICEX CRUISE

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LONG TERM GOALS

The primary goal of this research is to improve our understanding of those processes in the upper Arctic Ocean which influence the heat balance and sustain the ice cover. This goal encompasses the upper halocline and includes mesoscale features including their origins, prevalence, dynamics and influence on heat transport. A secondary role of this program is to participate in assessing the potential utility of submarines as research platforms.

OBJECTIVES

The following objectives contribute to attaining the primary goal:

(1) Obtain continuous underway measurement of the vertical distribution of horizontal currents in the upper Arctic Ocean from a submarine.
(2) Utilize the current observations to construct a statistically robust picture of vertical current shear in the Arctic Ocean halocline and, through comparison with temperature, salinity and density data, to assess the shear-driven turbulent vertical heat flux through the halocline and its variability.
(3) Correlate the measured currents with simultaneously measured temperature and salinity and use these results to identify and characterize upper ocean mesoscale features.
(4) Assess the distribution along the cruise tracks of upper ocean mesoscale features and estimate their influence on horizontal and vertical heat fluxes.

APPROACH

Vertical profiles of horizontal currents are measured continuously using an upward looking acoustic doppler current profiler (adcp) mounted on the foredeck, forward of the sail, on an underway submarine. The instrument used is a 150-kHz unit manufactured by RDI™. Both 4-m and 8-m vertical depth bins have been used, and a one-minute ensemble averaging interval is used providing adequate spatial resolution in view of the relatively high underway ship speeds. Information on ship speed, heading and geographical coordinates are provided as needed to correct the measured ship-relative currents to an earth-coordinate reference frame. Ancillary temperature (T) and salinity (S) data are acquired by separately funded investigators and provided to this program for use in the data analyses.

The integrated current, T and S datasets will be used, in conjunction with published theory, to compute vertical heat fluxes through the sampled upper halocline. These data will additionally be examined for current, T and S signatures, such as rotational currents and elevated core temperatures, that are known to typify mesoscale eddies. Results of these examinations will be used to ascertain the

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characteristics, number and distribution of eddies. Results of the eddy assessment will be used, in conjunction with the heat flux computations, to assess the impact of eddies on mixing. Finally, the current, T and S data will be used to locate frontal systems such as that historically associated with the Lomonosov Ridge and to assess possible interannual changes.

ACCOMPLISHMENTS

A satisfactory dataset was obtained from the USN submarine *Pogy* during the summer 1996 Submarine Arctic Science Cruise (SCICEX) to the Arctic Ocean. This dataset is somewhat of a landmark since it marks the first successful use, of which we are aware, of a submarine-mounted adcp. The primary data in this set consisted of continuous underway vertical current profiles measured using the upward-looking adcp. The data extended from about 8 m above the transducers, at a water depth typically of 100-150 m, to within 30-40 m of the sea ice cover. The adcp was used in "bottom-tracking" mode, and boat speed relative to that of the ice cover was measured as well as water column current profiles. The current data have been corrected for boat movement using the supplied navigational information. The data were also corrected using the boat speed measured relative to the ice cover in conjunction with known ice drift rates obtained from the Arctic Drift Buoy Program (Applied Physics Laboratory, Univ. of Washington). Ancillary data included ship speed, direction and position, and temperature and salinity data from both hull-mounted underway conductivity-temperature-depth recorders (CTDs) and frequent expendable conductivity-temperature-depth vertical profilers (XCTDs).

The USN submarine *Archerfish* is currently participating in the summer 1997 SCICEX program, and is due to return to port by mid-October. Data, including currents, T, S and navigational information, are being obtained in the same fashion as for the 1996 *Pogy* cruise. The related measurement systems checked out well during the predeployment scientific shakedown cruise. While there is no way to verify the data return and quality for the 1997 cruise until *Archerfish* makes port in mid-October 1997 and we have examined the data, we have every reason based on past performance and preliminary testing to expect a data return equally satisfactory to that from the 1996 cruise.

Finally, Mr. John Gunn of our office is participating, at present, as a Rider on the summer 1997 *Archerfish* cruise.

SCIENTIFIC/TECHNICAL RESULTS

Analyses of the summer 1996 SCICEX data are still in their early stages. These data were received in their entirety only in spring 1997, and preparation for and participation in the summer 1997 cruise has occupied much of the intervening time. Nonetheless, some preliminary results are available and are shown in Figures 1 and 2.

The summer 1996 adcp current data proved to be of high quality, and clearly show shear across the pycnocline (Figure 1). Additionally, they detected current signals associated with passage of the submarine through mesoscale eddies (Figure 1), although further eddy characterization will depend upon acquisition of final T and S data that have not yet been made available to this program.

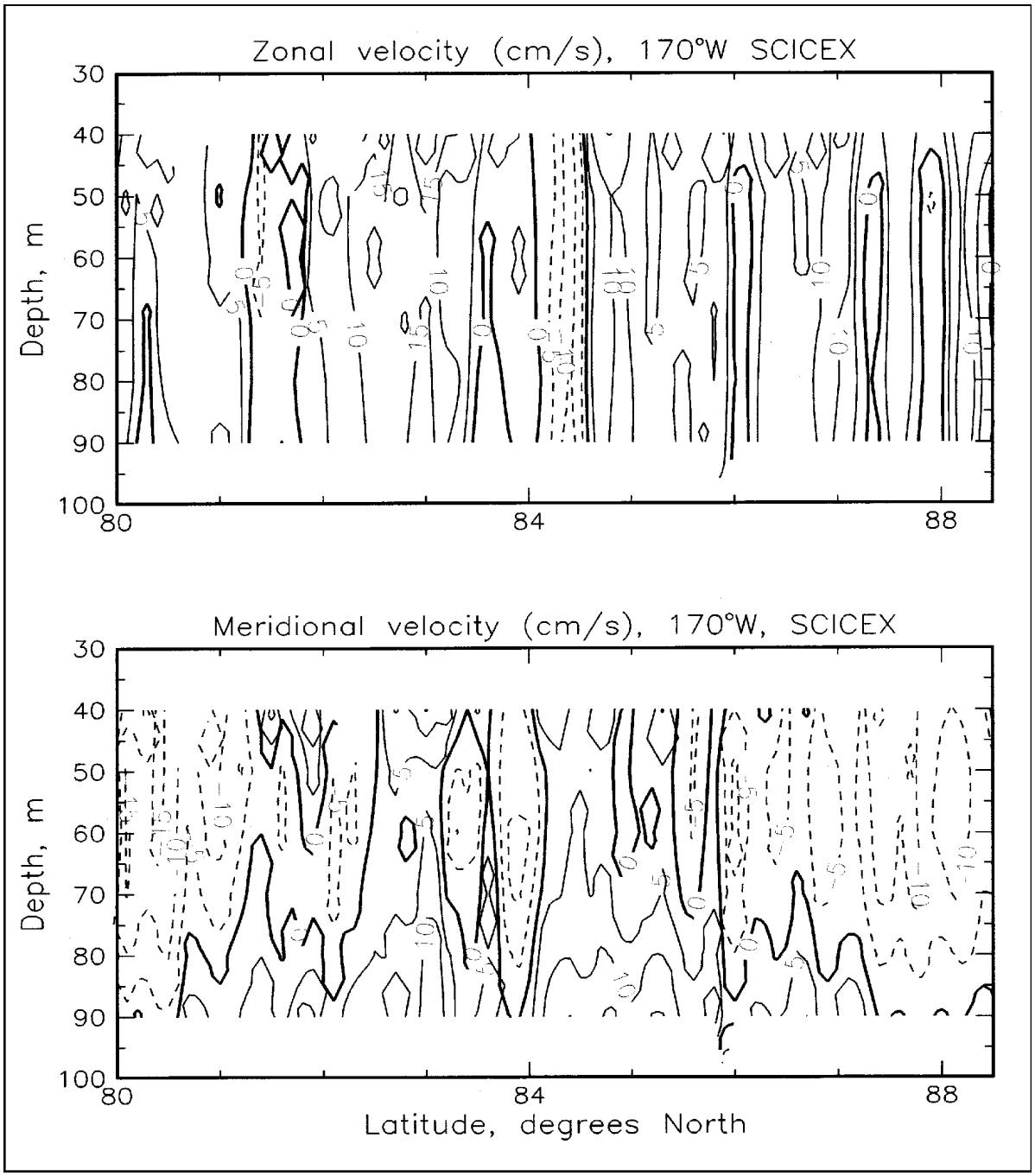

Figure 1. Preliminary plot showing the vertical distribution of earth-coordinate horizontal currents along a meridional transect obtained through the western Arctic Ocean using the adcp mounted aboard the USN submarine Pogy *during autumn 1996. The feature centered at about 84° latitude appears, because of its vertical extent and strong associated horizontal current shear, to be a cyclonic eddy. The concentration of vertical shear below about 60 m depths reflects presence of the halocline/pycnocline which is the locus of the strongest vertical shear. The bold contours indicates zero current speed, solid contours are positive (north and east), and dashed are negative (south and west).*

Semidiurnal (tidal or inertial) currents are also of interest. In a low energy environment such as the central Arctic Ocean basins, tidal and inertial currents are a potential energy source for turbulent mixing. Rigorous tidal analyses of underway adcp current records is not possible because the current sensor is moving through a geographically and temporally varying field. Further, tidal and inertial periods are similar at high latitudes. Such inertial currents, if sufficiently energetic, should be evident as inertial period vertical shear. The measured current velocity spectra show a significant peak at semidiurnal frequency, suggesting the presence in the central basin of appreciable tidal and/or inertial energy (Figure 2).

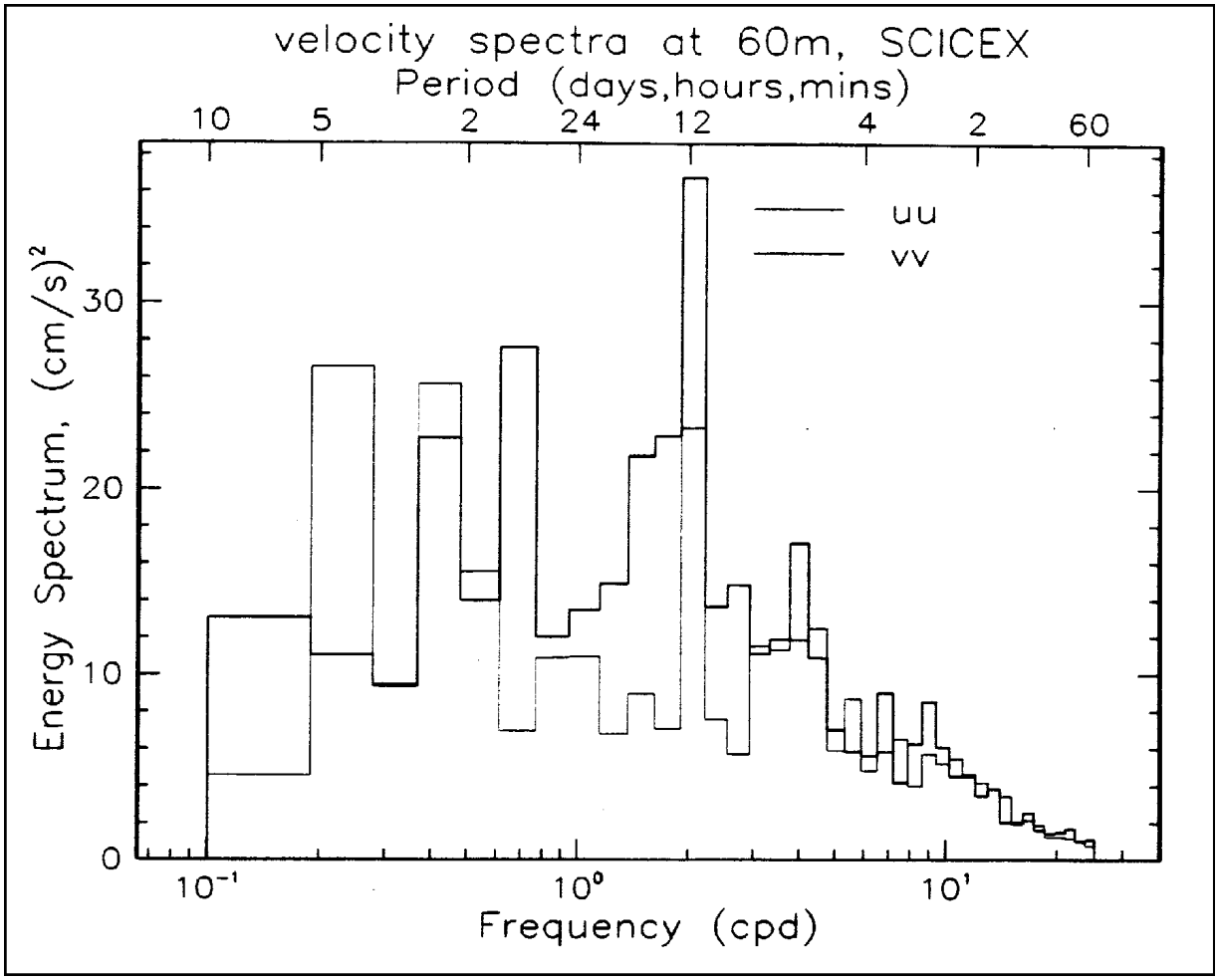

Figure 2. Preliminary energy spectra for the east-west (uu) and north-south (vv) earth-relative horizontal currents measured at a depth of 60 m from the Pogy *during autumn 1996. Note the semidiurnal (12 hour) peak, which likely represents a combination of tidal and inertial currents.*

IMPACT FOR SCIENCE (and/or) **SYSTEMS APPLICATIONS**

Our success in measuring vertical current profiles from an underway submarine using an adcp demonstrates that these vessels can be useful as oceanographic research platforms. This utility is underscored in regions inaccessible to conventional research vessels because of heavy surface ice cover. Comparatively high quality results can be obtained, when compared with a

surface vessel, because of the lack of wave-induced motions, bubbles and high vibration levels that are typically associated with surface vessels.

TRANSITIONS

The techniques being developed and employed during the SCICEX program for measurement of current profiles, temperature and salinity could be fruitfully utilized for submarine-based research in non-ice covered oceans. The current profile data are exceptionally clean. Additionally, cruising speeds high relative to those for oceanographic surface research vessels allow more intensive surveys and a closer approach to synoptic datasets.

RELATED PROJECTS

The Principal Investigator on this program participated in two related projects during FY1997. One project, funded by ONR and titled “Investigation of physical processes in the upper Arctic Ocean”, has as its goal to improve our documentation and understanding of the roles of small-scale and mesoscale processes within the Arctic Ocean system. This field-based program has approached its goal using data collected from surface platforms of opportunity. A second project, funded through ONR by the Arctic Nuclear Waste Assessment Program (ANWAP) and titled "Radionuclide transport pathways in the eastern Arctic Ocean", has provided funds during FY97 for ongoing analyses of T, S and current data obtained during 1993, 1995 and 1996 cruises of the *Polarstern* to the Arctic Ocean. The ANWAP project is concerned primarily with regional advective transports and with dispersion of possible waste materials. Consideration of mesoscale and smaller-scale processes is nonetheless necessary in order to explain aspects of the regional circulation and to understand and quantify dispersion processes.

REFERENCES:

Muench, R.D., Gunn, J.T., and Johnson, E.S., 1998: Current measurements from an underway submarine: preliminary results from the Arctic Ocean. *Eos*, 79 (Suppl.) (abstract submitted for presentation at AGU Ocean Sciences Meeting).